Environmental Science and Policy 92 (2019) 9–16

Contents lists available at ScienceDirect

Environmental Science and Policy

journal homepage: www.elsevier.com/locate/envsci

Constraints on farmer adaptability in the Iowa-Cedar River Basin

Patrick Bitterman*, David A. Bennett, Silvia Secchi

Department of Geographical and Sustainability Sciences, University of Iowa, United States

ARTICLE INFO

Keywords:
Adaptation
Climate change
Agricultural practices
Cluster analysis
Risk perception

ABSTRACT

Agricultural production and farmer wellbeing are frequently and adversely affected by interacting climatic, economic, and policy-related disturbances. The ability of individuals to adapt and manage their resilience in the face of these threats is key to understanding how social-ecological systems might respond to future disturbances. We report the results of a survey of farmer adaptability in the Iowa-Cedar River Basin in eastern Iowa that asked questions of farm characteristics, experiences with extreme events, risk perceptions, climate change beliefs, and the frequency of perturbations that might stimulate a response. We find that in general farmers' adoption of conservation practices and land use decisions are insensitive to climate-related perturbations. These individual adaptation decisions are affected by a wide array of constraints. Financial constraints and the stabilizing effect of crop insurance, in particular, reduce the self-reported likelihood that farmers will adapt to changes in system-level drivers. An analysis of constraints and farmer perturbation sensitivity suggests that alternative economic and policy levers may be necessary to incentivize change on the agricultural landscape.

1. Introduction

1.1. Agriculture and the Iowa-Cedar River Basin

Agriculture is threatened by climate change in many parts of the world (Intergovernmental Panel on Climate Change, 2014; National Research Council, 2010). Perturbations to agricultural systems at various spatial and temporal scales (e.g., crop failures, yield losses, soil degradation) can have ripple effects, leading to fluxes in local economic wellbeing, volatility in global commodity markets, and decreased food security. The agricultural social-ecological system (SES) in the Corn Belt of the United States is important to the food security of the nation and beyond, as well as the economic vitality and cultural identity of the region. However, industrial agriculture is facing a number of significant challenges, including feeding a growing and increasingly affluent population while managing land conversion and environmental degradation brought about by increasingly intensive production methods (Foley et al., 2011; Johnson et al., 2014). Demand for US corn is projected to continue to grow in the near future in part due to ethanol production (OCE, 2017). However, the agricultural practices that dominate the system and the landscape are causing rapid soil loss and widespread water pollution (Puckett, 1995; Syswerda et al., 2012), threatening the long-term sustainability of the system and of other systems to which it is connected (e.g., fisheries as a result of Gulf hypoxia (Rabalais et al., 2002)).

Global climate change is stimulating increased weather variability and has the potential to generate more frequent and severe weather events in the US Midwest and significantly perturb the agricultural SES (Hatfield et al., 2011). Genetic technologies have increased maize yields over the last 20 years, but cultivar sensitivity to drought stress has also increased (Lobell et al., 2014). While the exact impact and scale of climate effects is uncertain, recent droughts and excessive precipitation events (in 2012 and 2008, respectively) have at times significantly reduced crop yields and affected farmer income, emphasizing the role of crop insurance in providing coping capacity and stabilizing the system when perturbed (Mallya et al., 2013; Smith and Katz, 2013). Governmental policy (e.g., crop and income insurance), technologies (e.g., genetic modification of crops), and other in-field farmer adaptations (e.g., drainage tiling, irrigation) are examples of the adaptations undertaken to maintain agricultural yield and economic productivity. While effective in providing short-term stability and resilience to climatic disturbances, several of these adaptations potentially threaten the long-term sustainability of the SES by creating the institutions, infrastructure, technology, and incentives that produce system-level inertia and lead to "lock-in traps", perpetuating an unsustainable state (Allison and Hobbs, 2004; Orlove, 2005; Walker, 2000).

To better understand how farmers might respond to alternative adaptation strategies and policies, we must first ascertain the nature and degree of the actual and perceived constraints on their decision-

* Corresponding author.
E-mail address: patrick.bitterman@uvm.edu (P. Bitterman).

https://doi.org/10.1016/j.envsci.2018.11.004
Received 28 February 2018; Received in revised form 18 September 2018; Accepted 6 November 2018
Available online 16 November 2018
1462-9011/ © 2018 Elsevier Ltd. All rights reserved.

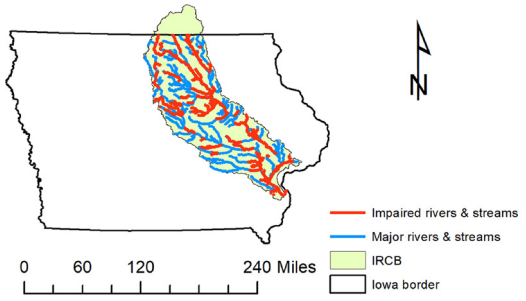

Fig. 1. The Iowa-Cedar River Basin and the impaired rivers and streams in the Iowa portion of the basin.

making processes. Further, we must understand these constraints in the climatic, economic, and social context within which farmers operate. For example, recent studies have found that beliefs in climate change and its anthropogenic causes are correlated to high levels of concern about future risks (Arbuckle et al., 2013b; Mase et al., 2016; Safi et al., 2012). The purpose of this study is to quantify farmer beliefs on climate change, constraints on their ability to adapt, and the stimuli required to promote alternative management practices. Accordingly, we address three research objectives. First, we measure the key constraints on individual farmer adaptability in the Iowa-Cedar River Basin (ICRB). Second, we gauge the necessary stimuli for farmers to consider these adaptations. Finally, we investigate how farmers' adaptability differs by experience and risk perceptions.

Our study area is the Iowa-Cedar River Basin in eastern Iowa (Fig. 1). The ICRB covers a spatial extent of approximately 59,400 km^2 in eastern Iowa and a small portion of Minnesota. It is home to about 31,000 farming operations (USDA, 2014), as well as many impaired rivers and streams (DNR, 2017). A 2011 survey of farmers in the Midwest Corn Belt found that ICRB farmers are on average more educated, more likely to retire in the next five years, and less likely to pass on their farm to their family than others in the Corn Belt (Loy et al., 2013). The same study also found that ICRB farms are on average smaller than others in the Corn Belt. Although the region has recently experienced significant drought and flooding (Schnoor, 2012), land use remains relatively stable, with approximately 70% of land planted in corn and soybeans. One reason for this stability is government programs, historically in the form of direct payments and now as federally-subsidized crop insurance. Under the Agricultural Act of 2014, crop insurance is heavily subsidized, with the most popular insurance program in Iowa guaranteeing farmers 86% of their benchmark revenue (USDA Farm Service Agency, 2016). This policy structure will remain in place until the implementation of the next Farm Bill (O'Donoghue et al., 2016).

1.2. Resilience and adaptability

This study, and the broader project of which it is a part, adopts a perspective on human-environment interaction and social-ecological systems grounded in the need to manage for change. This perspective is a central tenet of the social-ecological resilience paradigm and a useful way of conceptualizing human-environment interactions and their implications for human wellbeing and environmental health (Folke et al., 2010). We define resilience as the capacity of a SES to absorb or withstand perturbations and other stressors such that the system remains within the same regime, essentially maintaining its structure and functions (Walker et al., 2004). The management of resilience requires adaptive capacity, also called adaptability (Engle, 2011; Gallopín, 2006). Adaptability is a key component of the social-ecological resilience paradigm, and is defined as the ability of a SES to adjust its behavior to manage its resilience or to increase its coping range under existing or future conditions (Brooks and Adger, 2005; Folke et al., 2010; Walker et al., 2004). While adaptability describes a system-level ability to manage resilience, it is manifested by actors at various scales (e.g., individual, group, or system) that may act collectively (or in competition) to adapt to experienced, perceived, or expected changes. Understanding shifts in resilience, therefore, requires an examination of the incentives and constraints acting upon the agents that manage resilience or adaptation at multiple scales.

Barriers and hard limits on adaptive action may shrink the set of potential actions and reduce the adaptability of the system (Moser and Ekstrom, 2010). The relative strength of constraints can vary greatly by context – a result of a differential ability to overcome financial or regulatory barriers, or from group norms and individual beliefs. Adaptation can be limited by the willingness of individuals and groups to implement, manage, and accept an alternative. Willingness barriers can be rooted values and beliefs (Moser and Ekstrom, 2010), vested interests (Brooks and Adger, 2005), or the cognitive processes and biases that influence risk perception (Grothmann and Patt, 2005). For example, the way an individual values the environment is shaped by external factors (e.g., institutions, social norms) and internal processes (e.g., identity, utility) (van Riper et al., 2017). Smit and Pilfosova (2001) identify six determinants of adaptive capacity: economic resources, technology, infrastructure, information and skills, institutions, and equity. Fazey et al. (2007) further recognize four requirements of successful adaptation at the societal scale, including: will and intention, knowledge, proactive behavior, and the capacity to change. Aspects of these dimensions have been found at the institutional scale (Brooks et al., 2005; Gunderson et al., 2006; Gupta et al., 2010; Ostrom, 2010; Walker et al., 2004; Whitney et al., 2017), as well as individual and household scales (Adger et al., 2005; Grothmann and Patt, 2005; Kuruppu and Liverman, 2011; Oakes et al., 2016). Despite this work, there remains a need for empirical studies linking constraints on individual-scale adaptability to opportunities for possible policies that may affect system-scale resilience.

Agricultural decision-making is a complex process, where farmers with diverse characteristics and economic conditions integrate information from multiple sources, including their own experience, to project possible actions into an uncertain future with high stakes (Chatrchyan et al., 2017; Edwards-Jones, 2007). Goals of agricultural adaptation are highly context-dependent (Risbey et al., 1999), and may exist in response to changing climate or other objectives. In a review of conservation adoption research, Pannell et al. (2006) found that choice among alternative conservation practices depends on the ease of trialability and relative advantage. Haigh et al. (2015) detail the importance of geospatial specificity and timing in decision-making, both in the receipt of climate information and its application.

Adaptation in the agricultural sector is a global issue that has to be considered in different contexts with very different policy drivers, information levels and constraints. In reviewing case studies in less-developed countries (LDC), Vermeulen et al. (2013) show how decision robustness can be improved by engaging stakeholders and exploring uncertainty in climate impacts. Wood et al. (2014) find that access to weather information and assets have a positive impact on adaptation, though they caution that access differs greatly in LDC, and policies should be tailored to local context. An individual's perceptions of their own capacity for action can affect adaptive intentions as well (Kuruppu and Liverman, 2011).

In the context of Midwestern US agriculture, we need to better-understand how both hard and soft constraints affect the adaptive actions of farmers (Arbuckle et al., 2013a). In comparison with LDC, there is a much higher availability of weather and production related data, and a very active policy environment (or substantial levels of government support). With the recognition that adaptive process is iterative (Park et al., 2012) and that the range of potential constraints is large and diverse and that constraints are causally linked, we focus on the perspective of individual actors and their ability to overcome these constraints and realize individual and system-scale adaptability. It is

critical to concentrate on individual decision-making processes because the agricultural land in the Corn Belt is in private hands, it is managed through individual decisions, and US agricultural policy relies on voluntary incentives, often in the form of subsidies. The ability of the actors within the system to acquire knowledge is vital to increasing system-scale adaptability (Brooks and Adger, 2005; Nelson et al., 2007). If farmers in the ICRB were ignorant of the SES's function, including its history and potential for change, their management decisions and adaptations could fail. Farmers' choices also occur relative to their ability to marshal resources, including capital (both financial and social), natural resources, and human resources (Brooks et al., 2005; Brooks and Adger, 2005) to implement and maintain that adaption. Access to resources may be constrained by laws, geography, norms, and regulations, and therefore individual adaptive action must not be seen as autonomous, but rather shaped by social and institutional structures and context (Adger and Vincent, 2005).

The collective actions of farmers in the broader context of the ICRB shape the trajectory for both individual farmers and the SES. The identification of constraints on alternative adaptations is, therefore, necessary to alleviate those constraints and move the system towards more sustainable states. The availability of possible alternative pathways is important to long-term system sustainability, as adaptability has a direct effect on a system's ability to modify its exposure, sensitivity, or coping capacity (Smit and Wandel, 2006). Note, however, that it is possible for newly revealed alternatives to be less desirable, and the evaluation of alternatives in advance can avoid path dependence that might lock the system into an unsustainable trajectory. Further, while resilience is commonly assumed to be beneficial, it is value-neutral with respect to the desirability of a system state (Walker et al., 2004). Though the alleviation of constraints can reveal alternative pathways, adaptation might not occur without a stimulus. Here, we assume that an increase in the frequency and magnitude of climate perturbations will act against a risk threshold of farmers, causing them to act to reduce their risk exposure (Grothmann and Patt, 2005; Klein et al., 2014; Smithers and Smit, 1997). In a specified resilience frame, the nature, timing, and magnitude of a perturbation (e.g., a drought) can "push" an individual actor, or the SES, across this threshold and to an alternative state (Carpenter et al., 2001; Folke et al., 2010). This new state, however, may be less desirable, less resilient, or lead to lock-in traps preventing further adaptation (Allison and Hobbs, 2004; Nair and Howlett, 2016). By understanding farmers' perceptions, experiences, and constraints, we might also understand how they might react to future perturbations, and therefore design policy tools that avoid traps and guide the SES towards more desirable states.

2. Objectives, hypotheses, and experimental design

To quantify the state of farmer adaptability in the ICRB, farmers were surveyed and their responses analyzed using standard statistical and exploratory data techniques and ordered logistical regression. Our first objective is to quantify constraints on farmer adaptability from a variety of sources, including views on anthropogenic climate change, sources of coping capacity, and farmer characteristics. We focus on the factors that might constrain farmer decision-making and on the frequency of losses that would motivate them to consider adapting their land use. For example, with the passing of the 2014 US Farm Bill, US policy shifted from direct subsidies (e.g., commodity payments) to risk management and subsidized crop and income insurance. Given the programmatic shift, we expect crop insurance to be the primary coping mechanism used by farmers in the ICRB (Ifft et al., 2012). Further, we expect skepticism about climate change and lower perceptions of climate-related risk to be associated with greater adaptability constraints.

Accordingly, we test four alternative hypotheses to better understand the relationships between farmer experiences and their stated constraints on adaptations:

H1. *Increased perceptions of risk will be negatively associated with adaptability constraints;*

H2. *Past losses due to severe events will be negatively associated with adaptability constraints;*

H3. *Greater beliefs in anthropogenic sources of climate change will be negatively associated with adaptability constraints;*

H4. *Government-subsidized crop insurance is farmers' primary mechanism for coping with losses.*

These questions were designed to provide insight into the potential effects of incentives on different modes of farmer behavior, and to guide the empirical parameterization of decision models in future work.

3. Methods

The data were collected via a stratified random sample survey of farmers in the Iowa-Cedar River Basin. The sample of farmers was drawn from the USDA NASS dataset, which is the most current and inclusive list of farmers in the United States. The sample frame included farming operations within the ICRB and with more than 10 acres in operation. The survey was mailed to 1200 farmers in July of 2015. A follow-up copy of the survey was mailed a month later, and a final reminder postcard was sent shortly thereafter. In total, 275 completed surveys were received, resulting in a response rate of 23%. The survey included 62 questions, resulting in 251 variables coded in total. Among the questions asked were queries regarding land tenure and management, crop mix and yields, speed to adopt new practices, impacts on water quality, sources of information, demographics, income, and views on the nature of climate change. Further, respondents were asked to assign weights to economic, environmental, and social dimensions of sustainability. In this paper, we focus on questions of adaptation – particularly on those constraints that limit farmer adaptability, and on the level of perturbation required for farmers to consider an adaptation.

Table 1 details the five possible adaptations we asked ICB farmers to consider. Some fall under the umbrella of best management practices (BMPs), while others are more directly related to mitigating the effects of climate-related disturbances (i.e., irrigation, perennials, off-farm income). This distinction is geographically dependent (e.g., irrigation is largely unnecessary in IRCB rain-fed agriculture, but vital in other places), and there is overlap between environmental benefits of some

Table 1
Adaptations surveyed.

Adaptation	Description/example	Possible benefits
Conservation drainage	Water control structure holds water in fields when drainage is unnecessary	Reduces water outflow and nitrogen run-off from fields, improving water quality (Drury et al., 2009)
Irrigation	Direct application of water to crops	Improves yields in times of water scarcity (Li et al., 2007; Taylor and Young, 1995)
Increase organic material	Incorporation of plant and animal residue in soils	Provides nitrogen, reduces soil erosion, increases plant-available water
Perennial monoculture crop	Alternative perennial grass crop (e.g., switchgrass, Miscanthus)	Reduces impacts of droughts and extreme precipitation events (Barney et al., 2009)
Off-farm income	Supplemental income earned from off-farm labor	Increases financial coping capacity

practices (e.g., reduced run-off from perennial grasses) and their climate mitigating effects (e.g., reduced sensitivity to drought). For each adaptation, we asked two sets of follow-up questions. First, how frequently a severe event (e.g., drought, flood) would need to occur before the farmer considered that adaption. We offered two levels of magnitude, 30% and 50% yield losses, for each question. Possible answers ranged from "never adapt no matter what" to "once every 10 years," and included options for unsure, not relevant, and other. Second, we asked farmers to what degree their ability or willingness to seek the adaptation is constrained by: 1) finances, 2) time, 3) insufficient proof of benefit, 4) difficulty integrating with the current farming system, 5) lack of equipment, 6) professional support, or 7) environmental concerns.

All analyses were performed in R (R Core Team, 2017). Hypotheses 1–3 were tested using individual adaptability constraints (e.g., finances, time) as the dependent variable. Possible responses were presented to farmers in plain language, ranging from the level of "not at all" to "a lot", corresponding to codes 1–4. Farmers also had the option of selecting "don't know" or "does not apply", which occurred in approximately 10% of responses and were omitted from analysis as they do not fit on an ordinal scale. A similar recoding was performed on the frequency of extreme events necessary before a farmer would consider an adaptation. Farmer responses corresponding to "I would never adapt…" were coded as 0, such that the scale follows a coding pattern of increasing frequency: "never" (0), "annually" (1), … "every 10 years" (5) (see Table S1 in the supplemental materials).

We also asked farmers to select a statement that best reflected their beliefs about climate change. These answers were recoded following Arbuckle et al. (2014), which ranks responses from 0 (climate change is not occurring) to 1 (climate change is occurring, and is caused mostly by human activities). We followed this procedure to facilitate comparisons among similar farmer populations, and to place climate change beliefs on a quasi-ordinal scale. H1, H2, and H3 were tested with ordered logistic regression (OLR) because our response variables are generally not continuous and do not satisfy all of the assumptions of traditional parametric methods.

4. Results

We begin by exploring the views of IRCB farmers on climate change and its causes. Only 17.4% of ICRB farmers stated that climate change is occurring and is mostly caused by human activity (Fig. 2), a view consistent with scientific consensus (Intergovernmental Panel on Climate Change, 2014). However, we also find that 70% of the farmers agree that climate change is occurring, though farmers differ in their view of the sources. After recoding farmer responses (see Table S2), the mean value is 0.594, with a standard error of 0.020. These results are similar to the values found in Arbuckle et al. (2014).

Next, we investigate the key constraints on individual farmer adaptability based on recoded values for 7 constraints on each of the 5 possible adaptations. Using a Kruskal-Wallis test to compare constraints, we found the differences among groups to be statistically significant ($\chi^2 = 266.87$, $p < 0.001$), with financial constraints much higher than the others. In Fig. 3, we plot a heat map of mean constraint values, with darker shades corresponding to greater constraints. Constraint values are sorted such that the constraint with the greatest overall mean value is in the top row, and the most-constrained adaptation is on the left. The planting of perennial monoculture crops is the most constrained adaptation, followed by conservation drainage. Finances are the greatest constraint on all adaptations, suggesting that financial incentives could influence farmer behavior more than other factors. Lack of equipment and environmental concerns are omitted for the off-farm income constraint as they are not relevant to that particular adaptation.

Hypothesis 1 tests if increased perceptions of future risk are negatively associated with adaptability constraints. As we have 35 total combinations of possible adaptations and constraints (5 adaptations, 7 constraints each), 35 OLR models were created to measure the effects of risk perceptions, past losses, and climate change beliefs on each constraint. Given the size of the dataset, only statistically significant relationships are reported in Table 2. Perceptions of drought, extreme precipitation, and price volatility were used as independent variables.

Constraints on conservation drainage, irrigation, and increasing organic material in the soil were found to be statistically significant ($p < 0.05$). Perceptions of future drought and extreme precipitation were not found to be significant predictors of constraints. However, the risk of future price volatility is a statistically significant driver of constraints, meaning that as risk perceptions are greater, farmers feel more constrained and less able to adapt.

Hypotheses 2 and 3 use the same OLR models as in hypothesis 1, but instead investigate the effects of past losses and beliefs in anthropogenic climate change on constraint levels. Our results show positive relationships between past losses and greater constraints (Table 3). In particular, as the number of past precipitation events increases, the model predicts a greater chance of increased constraints on irrigation (integration and equipment) and organic material (finances). Past drought losses were significant predictors of constraints on conservation drainage (time, professional support), off-farm income, and financial constraints on irrigation. With respect to climate change beliefs in hypothesis 3, there is a negative association between increased beliefs in anthropogenic climate change and greater proof-of-benefit constrains on irrigation. Meaning, as beliefs in anthropogenic causes of climate increase, farmers are less likely to view proof of benefit as an impediment to implementing irrigation. While we can accept hypothesis 3 for this one adaptability constraint, we find no evidence that climate change beliefs are major drivers of the other constraints surveyed.

Hypothesis 4 investigates the distribution of coping capacity used by

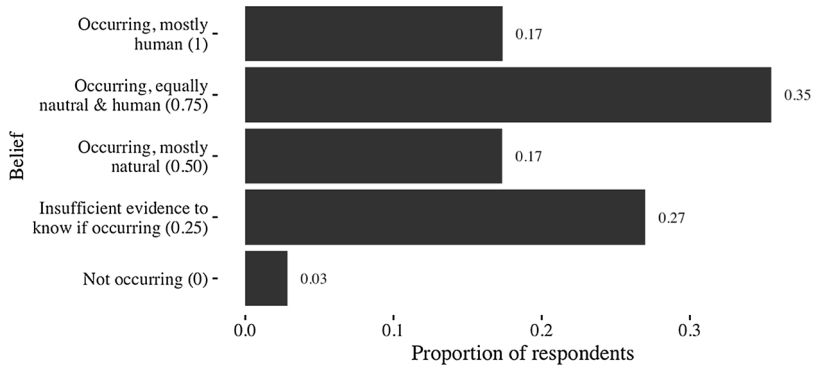

Fig. 2. Beliefs in climate change expressed by survey respondents. Values in parentheses correspond to the recoded values in the text. Values at the end of bars are rounded, and may not sum to 1.

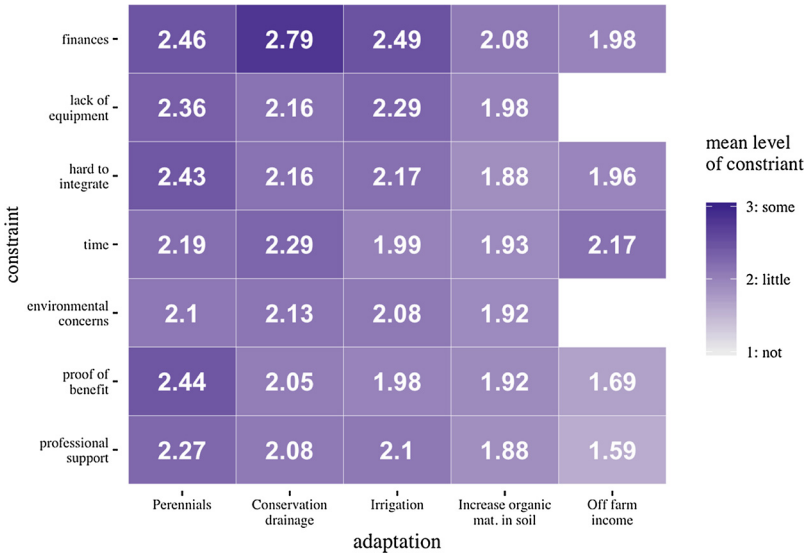

Fig. 3. Heat map of adaptation constraints. Levels of constraints follow a gradient of greatest to least from left-to-right and top-to-bottom.

farmers during the 5-year period 2010-2014. Respondents were able to choose more than one option, so the sum of proportions is greater than 1 (N = 244). As seen in Fig. 4, federally-subsidized crop insurance is by far the greatest source of coping capacity in ICRB farmers. This is consistent with a report published prior to the passing of the 2014 Farm Bill (Ifft et al., 2012), which concluded the elimination of the direct payments program would result in additional reliance on crop insurance. The dominance of crop insurance is confirmed by a chi-square test of the distribution of coping mechanisms ($p = 0.001$, $\chi^2 = 64.336$).

The above results indicate there are relationships among farmer beliefs, risk perceptions, and coping mechanisms that might lead to differential levels of constraints. A wide range of constraints affects farmer adaptation, with financial constraints consistently and significantly impacting farmer adaptation. Subsequent work will use these data in an agent-based model of farmer land use and the adoption of perennials monoculture crops. Accordingly, we are interested in the frequency of extreme event stimuli that farmers would require before considering the adaptations surveyed. These event frequencies are summarized in Fig. 5, which plots the weighted mean frequency of 50% yield losses for each adaptation.

Irrigation and the adoption of perennial monoculture crops have the greatest proportions of "I would never adopt…" responses. Over half of farmers state they would never consider or would require an annual 50% loss for three adaptations (perennials, off-farm income, and irrigation). Increasing organic soil materials and the installation of conservation drainage would require relatively less frequent perturbations. However, both still would require a 50% loss in every-other-year before being considered by farmers. In general, significant losses due to climatic events would need to occur with very high frequency before ICRB farmers would consider the five adaptations, if at all.

5. Discussion

Only about 17% of ICRB farmers attribute climate change solely to anthropogenic sources, though approximately 52% state it has some anthropogenic component. This latter percentage is greater than the 35% (in California) and 41% (in the US Midwest) values found in a review of similar surveys (Prokopy et al., 2015). However, we also find that the majority (70%) of farmers in the ICRB believe that climate change is occurring. Arbuckle et al. (2013b) similarly find that 68% of farmers state climate change is occurring. We modeled our climate change beliefs question on Arbuckle, so the similarity is unsurprising. The difference in beliefs in anthropogenic sources can be attributed to a slightly different sample of farmers – Arbuckle surveyed farmers across the Midwest, while we focused on a subset of the area.

Our results indicate these climate change beliefs have very little effect on farmer decision-making in the ICRB. Hypothesis 3 tested this relationship, finding only that the proof-of-benefit constraint on irrigation had any relationship with climate change beliefs. This suggests that when considering constraints, farmers are future-oriented, rather than integrating past events in their response. This finding is consistent with other studies, which have found that farmers do not weight climate change heavily or view it as a concern (Singh et al., 2018; White and Selfa, 2012), and that while farmers agree that climate change is occurring, they are skeptical of its causes (Chatrchyan et al., 2017). This uncertainty held by farmers regarding the causes of climate change and its impacts has been found to reduce motivation to adapt (Morton et al., 2017), though there is evidence to suggest that even if farmers do not explicitly acknowledge global climate concerns as a reason to adapt,

Table 2
Results of the ordinal logistic regression models for variables related to hypothesis 1. In all models, the only significant independent variable is the perception of future price risk.

Dependent variable	Coeff. estimate	SE	p	Odds ratio	Odds ratio 95% CI
Conservation drainage, finances	0.564	0.185	0.002	1.758	1.222 – 2.528
Conservation drainage, time	0.384	0.179	0.031	1.469	1.034 – 2.085
Irrigation, finances	0.396	0.181	0.028	1.486	1.043 – 2.116
Irrigation, equipment	0.377	0.172	0.029	1.457	1.038 – 2.045
Irrigation, prof. support	0.378	0.184	0.040	1.459	1.017 – 2.094
Organic material, finances	0.484	0.170	0.004	1.622	1.163 – 2.261
Organic material, time	0.366	0.182	0.044	1.443	1.100 – 2.061
Organic material, equipment	0.412	0.192	0.032	1.510	1.035 – 2.201

Table 3
Results of the ordinal logistic regression models for variables in hypotheses 2 and 3.

Dependent variable	Independent variable	Coeff. estimate	SE	p	Odds ratio	Odds ratio 95% CI
Conservation drainage, time	n droughts	0.595	0.285	0.037	1.813	1.038 – 3.167
Conservation drainage, prof. support	n droughts	0.764	0.309	0.013	2.145	1.171 – 3.932
Irrigation, finances	n droughts	0.813	0.276	0.003	2.256	1.314 – 3.872
Irrigation, equipment	n precip. events	0.386	0.158	0.015	1.471	1.079 – 2.004
Irrigation, integration	n precip. events	0.594	0.191	0.002	1.811	1.245 – 2.635
Organic material, finances	n precip. events	0.443	0.196	0.024	1.558	1.060 – 2.289
Off-farm income, professional support	n droughts	0.673	0.273	0.014	1.961	1.147 – 3.350
Irrigation, proof of benefit	climate change beliefs	−1.038	0.507	0.041	0.354	0.131 – 0.956

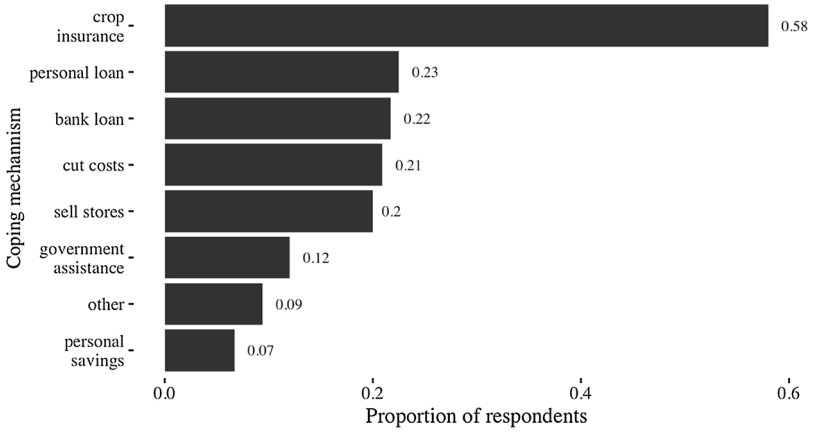

Fig. 4. Proportion of respondents that used each coping mechanism in 2010 – 2014. Responses were non-exclusive.

they do perceive local changes in climate and take steps to mitigate losses (Doll et al., 2017). This incongruence between beliefs and observed impacts can be explained by the co-occurrence of experiential learning and motivated reasoning, suggesting there is a feedback loop between issue engagement, experience, and beliefs (Myers, 2012; van der Linden, 2014).

We found that finances are the greatest constraint on all five adaptive options, and that those adaptations that would require the greatest resources (i.e., planting perennials, installation of conservation drainage, and irrigation) are also the most constrained options. The magnitudes of constraints are more similar by the type of adaptation, rather than the type of constraints. This underscores the limitation of the survey instrument and the interdependence of the constraints themselves. Proof-of-benefit could be interpreted by respondents, for example, as a financial burden, which was surveyed separately. Similarly, there are economic dimensions to integrating new practices and in developing additional professional support.

We found no relationship between perceptions of future climate-related risks and adaptation constraints. Price volatility risk, however, did predict constraints for irrigation, installing conservation drainage, and increasing organic material. These adaptations would require significant capital investments or changes in practices, and it is sensible that farmers perceiving additional market volatility would avoid such outlays. Our findings are somewhat surprising, and are inconsistent with studies that have found positive relationships between climate risk perceptions and adaptive actions (Blennow and Persson, 2009; Carlton et al., 2015; Grothmann and Patt, 2005; Mase et al., 2016). This inconsistency may be explained by the structure of our study and

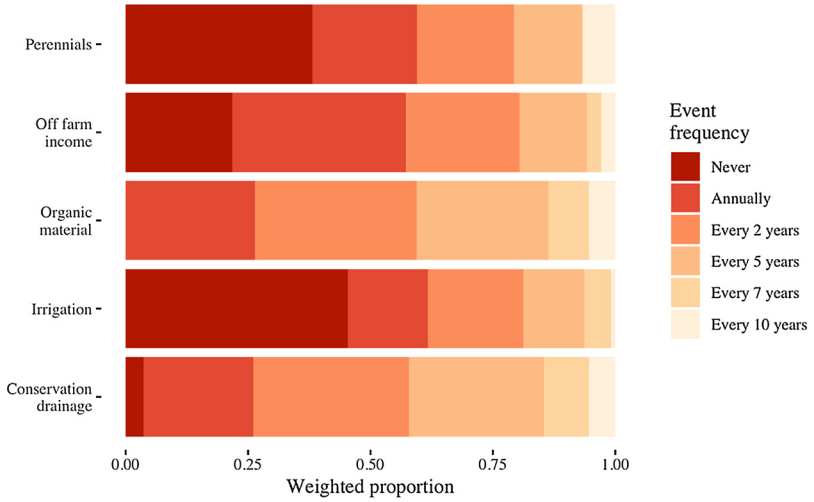

Fig. 5. The stated frequency of 50% losses needed for farmers to consider the adaptations included in the survey. Adaptations to irrigation and perennial crops would require more frequent perturbations than other options.

questionnaire. Instead of asking about adaptations themselves, or using empirical data on what farmers have actually implemented, we asked about constraints on those adaptations. Our intent was to understand what underlying issues prevent farmers from adapting. In one sense, we have ascribed these issues to financial constraints and price volatility. This suggests, however, that our set of constraints needs to be expanded and more nuanced to capture the complex dynamics of the decision process.

Prior losses were found to be weak predictors of adaptability constraints, with the exception of the two adaptations most closely related to water issues. Whether in the past, or potentially in the future, the threat of productivity loss does not appear to be a motivating factor for ICRB farmers. Over half of the respondents stated that 50% losses due to climate would need to occur at least every-other-year before they would try perennials, irrigation, or find off-farm employment. This seems counter-intuitive, as given low profit margins it is difficult for farms to absorb repeated losses and remain in business. It is possible that our respondents found such losses unlikely and answered the questions with these expectations in mind. However, in light of our findings vis-à-vis financial constraints and perceptions of price risk, it is possible that a loss of profitability, rather than productivity, might motivate farmers. This is complicated by the role of crop insurance, confirmed in H4 to be the most important coping mechanism for ICRB farmers in coping with yield losses. Crop insurance is designed to mitigate the financial impact of crop loss, and the distributions of event frequency (Fig. 5) indicate that the current state of the system is largely insensitive to productivity losses. We note, however, that this survey was conducted during the summer of 2015, which was after the passing of, and initial enrollment by farmers in, the 2014 Farm Bill. Given the changes in the legislation, while these data reflect past behavior and perceptions under the new legal and economic framework, our findings may not accurately predict future behavior under the new policy. However, if anything, given the removal of direct payments from the 2014 Farm Bill, reliance on federally-subsided crop insurance would likely increase. If adaptation isn't economically rational, farmers are unlikely to change their farming practices.

6. Conclusions

Our results confirm that financial concerns are the primary driver holding back adaptation in ICRB farmers, and that climate impacts do not account for behavior or risk perceptions. However, we also find that even farmers with low levels of constraints would require a very high rate of 50% losses before they would adapt. This seeming contradiction is explained by the efficacy of the federal crop insurance program, which ensures revenue even in years with low prices or low yields. Within the bounds of the five adaptations included in the survey, few farmers have taken steps to mitigate climate change risk. The adaptations that have been undertaken (off-farm income, increase organic material in soil, installation of conservation drainage) directly affect productivity and profitability in the current climate, and may increase resilience to future events. However, absent a change in land use or substantial technological change, fundamental variability in crop productivity will remain.

These results also suggest that policies designed to incentivize alternative land use must address the financial viability of potential adaptations, particularly given the stability granted by the insurance program. Future work will explore more deeply the connections between farmer adaptability and other survey questions not explored here. For example, the survey asked farmers to assign relative weights to three dimensions of sustainability, and further decomposed each dimension into sub-dimensions. The survey also indicates where additional work with farmers is necessary and will be used as a starting point for qualitative research into the interdependence of constraints and how decision-making processes integrate new information and change over time. The influence of the government has shaped incentives and markets, which have led to the current state of the agro-SES in the ICRB. While the system currently seems locked-in to its current state, and though there are many reasons to be skeptical of transformative change in the system, history has shown it possible.

Acknowledgements

This work was supported by NSF Coupled Natural Human Systems Award #1114978. People, Water, and Climate: Adaptation and Resilience in Agricultural Watersheds. Minor financial support was provided by NSF IGERT Award #0966130 and NSF OIA#01556770 at various stages of manuscript development and preparation.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.envsci.2018.11.004.

References

Adger, W.N., Arnell, N.W., Tompkins, E.L., 2005. Successful adaptation to climate change across scales. Glob. Environ. Chang. Part A 15, 77–86. https://doi.org/10.1016/j.gloenvcha.2004.12.005.

Adger, W.N., Vincent, K., 2005. Uncertainty in adaptive capacity. Comptes Rendus Geosci. 337, 399–410. https://doi.org/10.1016/j.crte.2004.11.004.

Allison, H.E., Hobbs, R.J., 2004. Resilience, adaptive capacity, and the lock-in trap of the Western Australian agricultural region. Ecol. Soc. 9, 3.

Arbuckle, J.G., Hobbs, J., Loy, A., Morton, L.W., Prokopy, L.S., Tyndall, J., 2014. Understanding Corn Belt farmer perspectives on climate change to inform engagement strategies for adaptation and mitigation. J. Soil Water Conserv. 69, 505–516. https://doi.org/10.2489/jswc.69.6.505.

Arbuckle, J.G., Morton, L.W., Hobbs, J., 2013a. Farmer beliefs and concerns about climate change and attitudes toward adaptation and mitigation: evidence from Iowa. Clim. Change 118, 551–563. https://doi.org/10.1007/s10584-013-0700-0.

Arbuckle, J.G., Prokopy, L.S., Haigh, T., Hobbs, J., Knoot, T., Knutson, C., Loy, A., Mase, A.S., McGuire, J., Morton, L.W., Tyndall, J., Widhalm, M., 2013b. Climate change beliefs, concerns, and attitudes toward adaptation and mitigation among farmers in the Midwestern United States. Clim. Change 117, 943–950. https://doi.org/10.1007/s10584-013-0707-6.

Barney, J.N., Mann, J.J., Kyser, G.B., Blumwald, E., Van Deynze, A., DiTomaso, J.M., 2009. Tolerance of switchgrass to extreme soil moisture stress: ecological implications. Plant Sci. 177, 724–732. https://doi.org/10.1016/j.plantsci.2009.09.003.

Blennow, K., Persson, J., 2009. Climate change: motivation for taking measure to adapt. Glob. Environ. Chang. Part A 19, 100–104. https://doi.org/10.1016/j.gloenvcha.2008.10.003.

Brooks, N., Adger, W.N., 2005. Assessing and enhancing adaptive capacity. In: Lim, B., Spanger-Siegfried, E. (Eds.), Adaptation Policy Frameworks for Climate Change Developing Strategies, Policies and Measures. Cambridge, pp. 165–181.

Brooks, N., Adger, W.N., Mick Kelly, P., 2005. The determinants of vulnerability and adaptive capacity at the national level and the implications for adaptation. Glob. Environ. Change Part A 15, 151–163. https://doi.org/10.1016/j.gloenvcha.2004.12.006.

Carlton, J.S., Mase, A.S., Knutson, C.L., Lemos, M.C., Haigh, T., Todey, D.P., Prokopy, L.S., 2015. The effects of extreme drought on climate change beliefs, risk perceptions, and adaptation attitudes. Clim. Change 135, 211–226. https://doi.org/10.1007/s10584-015-1561-5.

Carpenter, S., Walker, B., Anderies, J.M., Abel, N., 2001. From metaphor to measurement: resilience of what to what? Ecosystems 4, 765–781. https://doi.org/10.1007/si0021-001-0045-9.

Chatrchyan, A.M., Erlebacher, R.C., Chaopricha, N.T., Chan, J., Tobin, D., Allred, S.B., 2017. United States agricultural stakeholder views and decisions on climate change. WIREs Clim. Change 8https://doi.org/10.1002/wcc.469. e469–21.

DNR, 2017. Impaired Waters [WWW Document]. URL. Iowa Department of Natural Resources (Accessed 4.10.17). http://www.iowadnr.gov/Environmental-Protection/Water-Quality/Water-Monitoring/Impaired-Waters.

Doll, J.E., Petersen, B., Bode, C., 2017. Skeptical but adapting: what Midwestern farmers say about climate change. Weather Clim. Soc. 9, 739–751. https://doi.org/10.1175/WCAS-D-16-0110.1.

Drury, C.F., Tan, C.S., Reynolds, W.D., Welacky, T.W., Oloya, T.O., Gaynor, J.D., 2009. Managing tile drainage, subirrigation, and nitrogen fertilization to enhance crop yields and reduce nitrate loss. J. Environ. Qual. 38https://doi.org/10.2134/jeq2008.0036. 1193–12.

Edwards-Jones, G., 2007. Modelling farmer decision-making: concepts, progress and challenges. ASC 82, 783–789. https://doi.org/10.1017/ASC2006112.

Engle, N.L., 2011. Adaptive capacity and its assessment. Glob. Environ. Change Part A 21, 647–656. https://doi.org/10.1016/j.gloenvcha.2011.01.019.

Fazey, I., Fazey, J.A., Fischer, J., Sherren, K., Nose, R.F., Dovers, S.R., 2007. Adaptive capacity and learning to learn as leverage for social–ecological resilience. Front. Ecol. Environ. 5, 375–380.

Foley, J.A., Foley, J.A., Ramankutty, N., Brauman, K.A., Cassidy, E.S., Gerber, J.S., Johnston, M., Mueller, N.D., O'Connell, C., Ray, D.K., West, P.C., Balzer, C., Bennett, E.M., Carpenter, S.R., Hill, J., Monfreda, C., Polasky, S., Rockström, J., Sheehan, J., Siebert, S., Tilman, D., Zaks, D.P.M., 2011. Solutions for a cultivated planet. Nature

478, 337–342. https://doi.org/10.1038/nature10452.
Folke, C., Carpenter, S., Walker, B., Scheffer, M., Chapin, T., Rockstrom, J., 2010. Resilience thinking: integrating resilience, adaptability and transformability. Ecol. Soc. 15, 9.
Gallopín, G.C., 2006. Linkages between vulnerability, resilience, and adaptive capacity. Glob. Environ. Change Part A 16, 293–303. https://doi.org/10.1016/j.gloenvcha.2006.02.004.
Grothmann, T., Patt, A., 2005. Adaptive capacity and human cognition: the process of individual adaptation to climate change. Glob. Environ. Change Part A 15, 199–213. https://doi.org/10.1016/j.gloenvcha.2005.01.002.
Gunderson, L.H., Carpenter, S., Folke, C., Olsson, P., Peterson, G., 2006. Water RATs (resilience, adaptability, and transformability) in lake and wetland social-ecological systems. ES 11, 16.
Gupta, J., Termeer, C., Klostermann, J., Meijerink, S., van den Brink, M., Jong, P., Nooteboom, S., Bergsma, E., 2010. The adaptive capacity wheel: a method to assess the inherent characteristics of institutions to enable the adaptive capacity of society. Environ. Sci. Policy 13, 459–471. https://doi.org/10.1016/j.envsci.2010.05.006.
Haigh, T., Takle, E., Andresen, J., Widhalm, M., Carlton, J.S., Angel, J., 2015. Mapping the decision points and climate information use of agricultural producers across the U.S. Corn Belt. Clim. Risk Manage. 7, 20–30. https://doi.org/10.1016/j.crm.2015.01.004.
Hatfield, J.L., Boote, K.J., Kimball, B.A., Ziska, L.H., Izaurralde, R.C., Ort, D., Thomson, A.M., Wolfe, D., 2011. Climate impacts on agriculture: implications for crop production. Agron. J. 103, 351–370. https://doi.org/10.2134/agronj2010.0303.
Ifft, J., Nickerson, C., Kuethe, T., You, C., 2012. Potential farm-level effects of eliminating direct payments. Econ. Inf. Bull. https://doi.org/10.2139/ssrn.2182028.
Intergovernmental Panel on Climate Change, 2014. Climate Change 2014–Impacts, Adaptation and Vulnerability: Regional Aspects. Cambridge University Press.
Johnson, J.A., Runge, C.F., Senauer, B., Foley, J., Polasky, S., 2014. Global agriculture and carbon trade-offs. PNAS 111, 12342–12347. https://doi.org/10.1073/pnas.1412835111.
Klein, R., Midgley, G.F., Preston, B.L., Alam, M., Berkhout, F.G.H., Dow, K., Shaw, M.R., 2014. Adaptation opportunities, constraints, and limits. In: Field, C.B., Barros, V.R., Dokken, D.J., Mach, K.J., Mastrandrea, M.D., Bilir, T.E., Chatterjee, M., Ebi, K.L., Estrada, Y.O., Genova, R.C., Girma, B., Kissel, E.S., Levy, A.N., MacCraken, S., Mastrandrea, P.R., White, L.L. (Eds.), Climate Change Impacts, Adaptation, and Vulnerability. Part a Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambride University Press, Cambridge, UK, pp. 899–943.
Kuruppu, N., Liverman, D., 2011. Mental preparation for climate adaptation: the role of cognition and culture in enhancing adaptive capacity of water management in Kiribati. Glob. Environ. Change Part A 21, 657–669. https://doi.org/10.1016/j.gloenvcha.2010.12.002.
Li, F., Liang, J., Kang, S., Zhang, J., 2007. Benefits of alternate partial root-zone irrigation on growth, water and nitrogen use efficiencies modified by fertilization and soil water status in maize. Plant Soil 295, 279–291. https://doi.org/10.1007/s11104-007-9283-8.
Lobell, D.B., Roberts, M.J., Schlenker, W., Braun, N., Little, B.B., Rejesus, R.M., Hammer, G.L., 2014. Greater sensitivity to drought accompanies maize yield increase in the U.S. Midwest. Science 344, 516–519. https://doi.org/10.1126/science.1251423.
Loy, A., Hobbs, J., Arbuckle Jr, J.G., Morton, L.W., Prokopy, L.S., Haigh, T., Knoot, T., Knutson, C., Mase, A.S., McGuire, J., Tyndall, J., Widhalm, M., 2013. Farmer Perspectives on Agriculture and Weather Variability in the Corn Belt: A Statistical Atlas. CSCAP 0153-2013). Climate Change, Mitigation, and Adaptation in Corn-based Cropping Systems, Ames, IA.
Mallya, G., Zhao, L., Song, X.C., Niyogi, D., Govindaraju, R.S., 2013. 2012 midwest drought in the United States. J. Hydrol. Eng. 18, 737–745. https://doi.org/10.1061/(ASCE)HE.1943-5584.0000786.
Mase, A.S., Gramig, B.M., Prokopy, L.S., 2016. Climate change beliefs, risk perceptions, and adaptation behavior among Midwestern U.S. Crop farmers. Clim. Risk Manage. 15, 8–17. https://doi.org/10.1016/j.crm.2016.11.004.
Morton, L.W., Roesch-McNally, G., Wilke, A.K., 2017. Upper Midwest farmer perceptions: Too much uncertainty about impacts of climate change to justify changing current agricultural practices. J. Soil Water Conserv. 72, 215–225. https://doi.org/10.2489/jswc.72.3.215.
Moser, S.C., Ekstrom, J.A., 2010. A framework to diagnose barriers to climate change adaptation. PNAS 107, 22026–22031.
Myers, T.A., 2012. The relationship between personal experience and belief in the reality of global warming. Nat. Clim. Change 3, 343–347. https://doi.org/10.1038/nclimate1754.
Nair, S., Howlett, M., 2016. From robustness to resilience: avoiding policy traps in the long term. Sustain Sci. 11, 1–9. https://doi.org/10.1007/s11625-016-0387-z.
National Research Council, 2010. Adapting to the Impacts of Climate Change. The National Academies Press, Washington, DC.
Nelson, D.R., Adger, W.N., Brown, K., 2007. Adaptation to environmental change: contributions of a resilience framework. Annu. Rev. Environ. Resourc. 32, 395–419. https://doi.org/10.1146/annurev.energy.32.051807.090348.
O'Donoghue, E.J., Hungerford, A.E., Cooper, J.C., Worth, T., Ash, M., 2016. The 2014 farm act agriculture risk coverage, price loss coverage, and supplemental coverage option programs' effects on crop revenue. Econ. Res. Serv.
Oakes, L.E., Ardoin, N.M., Lambin, E.F., 2016. "I know, therefore I adapt?" Complexities of individual adaptation to climate-induced forest dieback in Alaska. ES 21https://doi.org/10.5751/ES-08464-210240. art40–26.
OCE, 2017. USDA Agricultural Projections to 2026 (No. OCE-2017-1). USDA.
Orlove, B., 2005. Human adaptation to climate change: a review of three historical cases and some general perspectives. Environ. Sci. Policy 8, 589–600. https://doi.org/10.1016/j.envsci.2005.06.009.
Ostrom, E., 2010. Polycentric systems for coping with collective action and global environmental change. Glob. Environ. Change Part A 20, 550–557. https://doi.org/10.1016/j.gloenvcha.2010.07.004.
Pannell, D.J.R.M.G., Barr, N., Curtis, A., Vanclay, F., Wilkinson, R., 2006. Understanding and promoting adoption of conservation practices by rural landholders. Aust. J. Exp. Agric. 1407–1424. https://doi.org/10.1071/EA5037.
Park, S.E., Marshall, N.A., Jakku, E., Dowd, A.M., Howden, S.M., Mendham, E., Fleming, A., 2012. Informing adaptation responses to climate change through theories of transformation. Glob. Environ. Change Part A 22, 115–126. https://doi.org/10.1016/j.gloenvcha.2011.10.003.
Prokopy, L.S., Arbuckle, J.G., Barnes, A.P., Haden, V.R., Hogan, A., Niles, M.T., Tyndall, J., 2015. Farmers and climate change: a cross-national comparison of beliefs and risk perceptions in high-income countries. Environ. Manage. 56, 492–504. https://doi.org/10.1007/s00267-015-0504-2.
Puckett, L.J., 1995. Identifying the major sources of nutrient water pollution. Environ. Sci. Technol. 29, 408A–414A. https://doi.org/10.1021/es00009a001.
R Core Team, 2017. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org.
Rabalais, N.N., Turner, R.E., Wiseman Jr, W.J., 2002. Gulf of Mexico hypoxia, A.K.A. "The dead zone.". Annu. Rev. Ecol. Syst. 33, 235–263. https://doi.org/10.1146/annurev.ecolsys.33.010802.150513.
Risbey, J., Kandlikar, M., Dowlatabadi, H., Graetz, D., 1999. Scale, context, and decision making in agricultural adaptatoin to climate variability and change. Mitigation and Adaptatoin Strategies for Global Change. pp. 137–165.
Safi, A.S., Smith, W.J., Liu, Z., 2012. Rural Nevada and climate change: vulnerability, beliefs, and risk perception. Risk Anal. 32, 1041–1059. https://doi.org/10.1111/j.1539-6924.2012.01836.x.
Schnoor, J.L., 2012. The U.S. Drought of 2012. Environ. Sci. Technol. 46https://doi.org/10.1021/es303416z. 10480–10480.
Singh, A.S., Eanes, F.R., Prokopy, L.S., 2018. Assessing conservation adoption decision criteria using the analytic hierarchy process: case studies from three midwestern watersheds. Soc. Nat. Resour. 31, 503–507. https://doi.org/10.1080/08941920.2017.1413694.
Smit, B., Pilifosova, O., 2001. Adaptation to climate change in the context of sustainable development and equity. In: McCarthy, J.J., Canziani, O.F., Leary, N.A., Dokken, D.J., White, K.S. (Eds.), Climate Change Impacts, Adaptation and Vulnerability. IPCC Working Group II, pp. 877–912.
Smit, B., Wandel, J., 2006. Adaptation, adaptive capacity and vulnerability. Glob. Environ. Change Part A 16, 282–292. https://doi.org/10.1016/j.gloenvcha.2006.03.008.
Smith, A.B., Katz, R.W., 2013. US billion-dollar weather and climate disasters: data sources, trends, accuracy and biases. Nat. Hazards Dordr. (Dordr) 67, 387–410. https://doi.org/10.1007/s11069-013-0566-5.
Smithers, J., Smit, B., 1997. Human adaptation to climatic variability and change. Glob. Environ. Change Part A 7, 129–146. https://doi.org/10.1016/S0959-3780(97)00003-4.
Syswerda, S.P., Basso, B., Hamilton, S.K., Tausig, J.B., Robertson, G.P., Robertson, G.P., 2012. Long-term nitrate loss along an agricultural intensity gradient in the Upper Midwest USA. Agric. Ecosyst. Environ. 149, 10–19. https://doi.org/10.1016/j.agee.2011.12.007.
Taylor, R.G., Young, R.A., 1995. Rural-to-Urban water transfers: measuring direct. J. Agric. Resour. Econ. 20, 247–262.
USDA, 2014. 2012 Census of Agriculture (No. AC-12-A-15). United States Department of Agriculture.
USDA Farm Service Agency, 2016. ARC/PLC Program Landing Page [WWW Document]. USDA-Farm Service Agency URL https://www.fsa.usda.gov/programs-and-services/arcplc_program/ (accessed 11.16).
van der Linden, S., 2014. On the relationship between personal experience, affect and risk perception:The case of climate change. Eur. J. Soc. Psychol. 44, 430–440. https://doi.org/10.1002/ejsp.2008.
van Riper, C.J., Landon, A.C., Kidd, S., Bitterman, P., Fitzgerald, L.A., Granek, E.F., Ibarra, S., Iwaniec, D., Raymond, C.M., Toledo, D., 2017. Incorporating sociocultural phenomena into ecosystem-service valuation: the importance of critical pluralism. BioScience 67, 1–12. https://doi.org/10.1093/biosci/biw170.
Vermeulen, S.J., Challinor, A.J., Thornton, P.K., Campbell, B.M., Eriyagama, N., Vervoort, J.M., Kinyangi, J., Jarvis, A., Laderach, P., Ramirez-Villegas, J., Nicklin, K.J., Hawkins, E., Smith, D.R., 2013. Addressing uncertainty in adaptation planning for agriculture. Proc. Natl. Acad. Sci. U. S. A. 110, 8357–8362. https://doi.org/10.1073/pnas.1219441110.
Walker, B., Holling, C.S., Carpenter, S., Kinzig, A., 2004. Resilience, adaptability and transformability in social–ecological systems. ES 9, 5.
Walker, W., 2000. Entrapment in large technology systems: institutional commitment and power relations. Res. Policy 29, 833–846. https://doi.org/10.1016/S0048-7333(00)00108-6.
White, S.S., Selfa, T., 2012. Shifting lands: exploring kansas farmer decision-making in an era of climate change and biofuels production. Environ. Manage. 51, 379–391. https://doi.org/10.1007/s00267-012-9991-6.
Whitney, C.K., Bennett, N.J., Ban, N.C., Allison, E.H., Armitage, D., Blythe, J.L., Burt, J.M., Cheung, W., Finkbeiner, E.M., Kaplan-Hallam, M., Perry, I., Turner, N.J., Yumagulova, L., 2017. Adaptive capacity: from assessment to action in coastal social-ecological systems. ES 22, 22. https://doi.org/10.5751/ES-09325-220222.
Wood, S.A., Jina, A.S., Jain, M., Kristjanson, P., Defries, R.S., 2014. Smallholder farmer cropping decisions related to climate variability across multiple regions. Glob. Environ. Change Part A 25, 163–172. https://doi.org/10.1016/j.gloenvcha.2013.12.011.